Performance and Parametric Study of PHASE CHANGE MATERIAL (PCM) Solidification & Melting in Solar Thermal Evacuated Tube

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Outline

INTRODUCTION

PHYSICAL & NUMERICAL MODELLING

EXPERIMENTAL VERIFICATION AND VALIDATION

PARAMETRIC RESULTS AND DISCUSSION

Introduction

Solar thermal energy to heat domestic hot water is one of numerous researches that have high potential and that lead us towards the correct direction in shifting to renewable energy source

Study presents a numerical parametric study of a solar thermal evacuated system using phase change material (PCM)

- Laminar water flow as heat transfer fluid (HTF) and natural convection were considered for the numerical simulation

U – Tube design flow and concentric design flow were study combine the effect of design PCM tube design and system operating parameter on its thermal storage capacity using r ANSYS Workbench version 17.2.

current research studies, take different design parameters into consideration

- For design parameters, the effects of length and diameter of the PCM container on PCM heat storage capacity are studied

Many storage system geometries have been considered- vertical cylindrical containers and multi-tube arrays have been shown to be the best geometry for enhancing heat transfer due to the large heat transfer surface area and the presence of natural convection

SOLAR EVACUATED TUBE HOT WATER SYSTEM

METHODOLOGY

To develop 3D simulations model to study phase transition characteristic of PCMs, melting, solidification temperature and time required for those processes

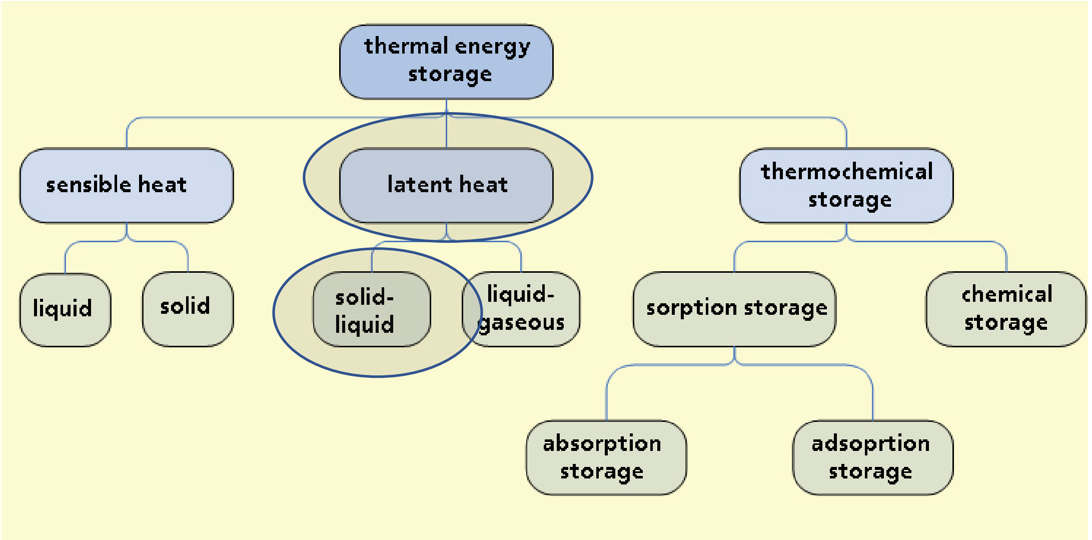
To design and fabricate the integrated solar collector with PCMs

To evaluate experimentally the performance of the thermal energy storage system

3 model size of solar thermal collector and its efficiency	2 different design of copper piping strategy - (concentric and dual flow)

To analysis different missions such as duration of charging/discharging cycles, thermal energy storage density

Latent Heat Energy Storage



Latent heat is the energy released or absorbed by a body or a thermodynamic system during a constant-temperature process

Property	RT82
Density of PCM, solid,ρs (kg/m^3)	950
Density of PCM, liquid, ρl (kg/m^3)	770
Specific heat of PCM, cpl (J/kg. K)	2000
Latent heat of fusion, L (J/kg)	176000
Melting temperature, Tm (°C)	78-82
Thermal conductivity, k (W/m.K)	0.2
Thermal expansion coefficient (1/K)	0.001
Dynamic Viscosity,μ (kg/m.s)	0.03499

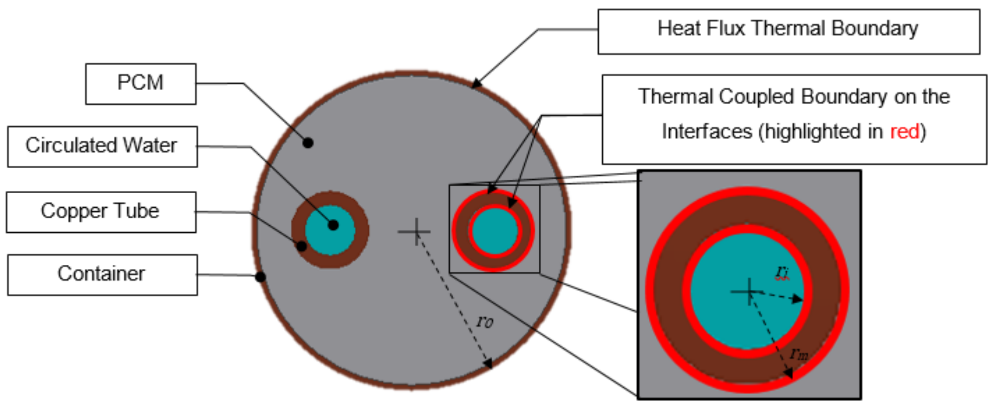
Source :http://www.rubitherm.de/english/download/Techdata_%20RT82_EN.PDF

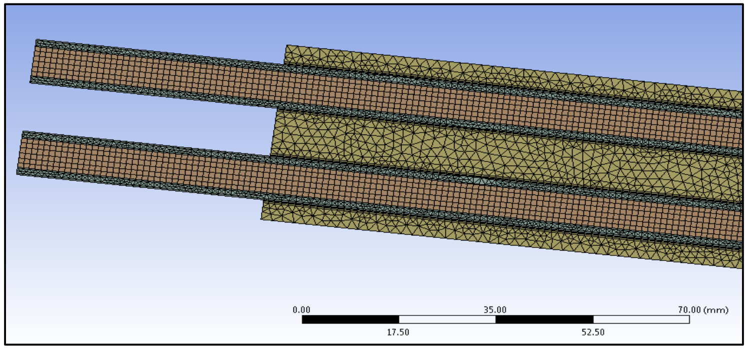
Physical and Numerical Modelling

The following assumption has been made to simplify the simulation :

- Thermal resistances of the container and u-tubes & concentric, as well as the viscous dissipation, are negligible.
- The effect of natural convection during melting is considerable
- The thermophysical properties of the HTF and PCMs are independent of temperature

Boundary Condition

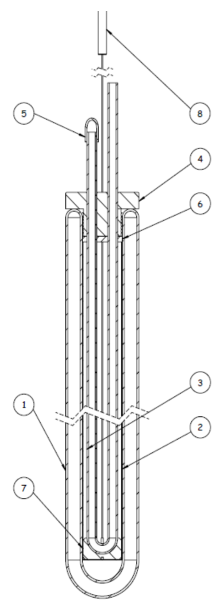


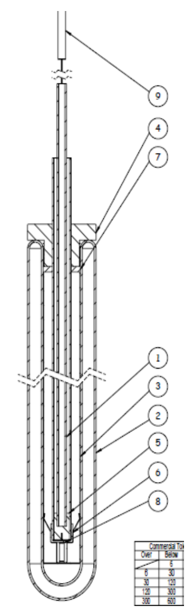


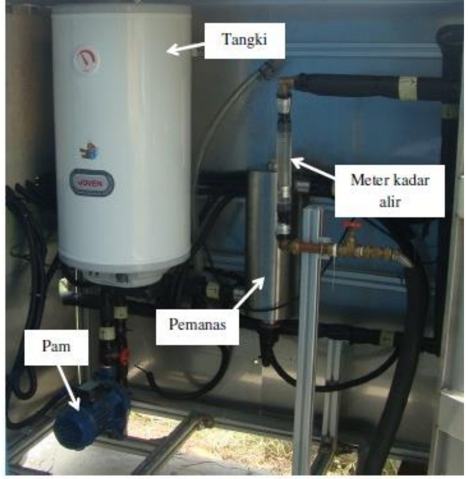
Mesh Configuration for Grid Independent Test

Grid Nomenclature	Mesh Nodes Count	Mesh Elements Count
C	376K	1.41M
M	615K	2.12M
F	1032K	3.61M

Experimental Verification And Validation

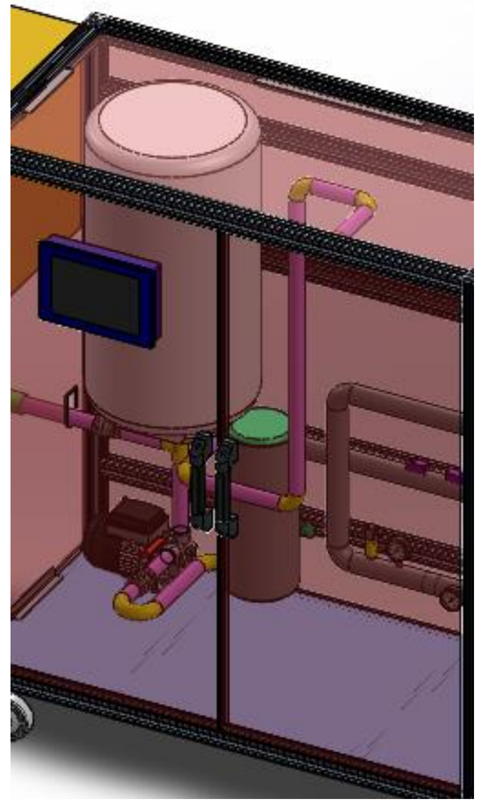






(a)

(b)



- FIELD INSTRUMENT

Parametric Result and Discussion

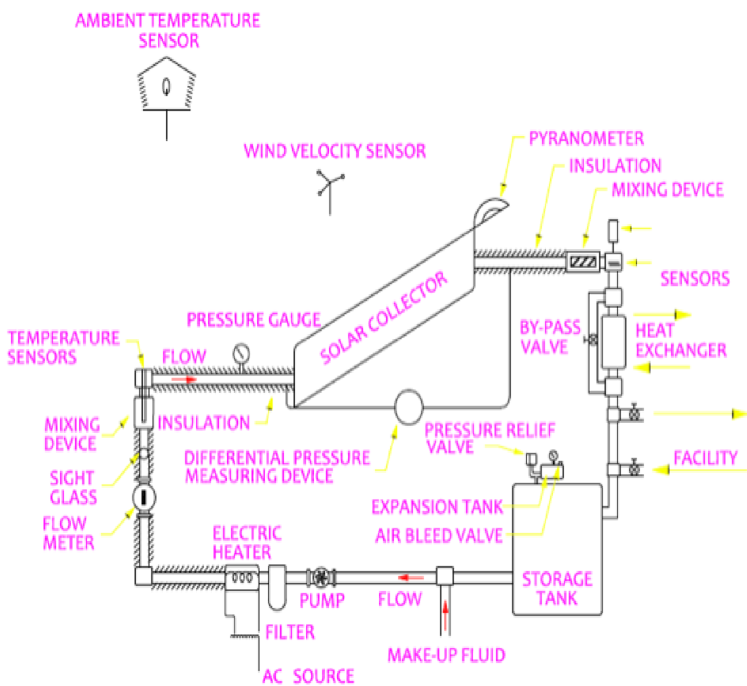


Figure 3.1: Experimental Solar Thermal Evacuated Tube with PCM Schematic Diagram

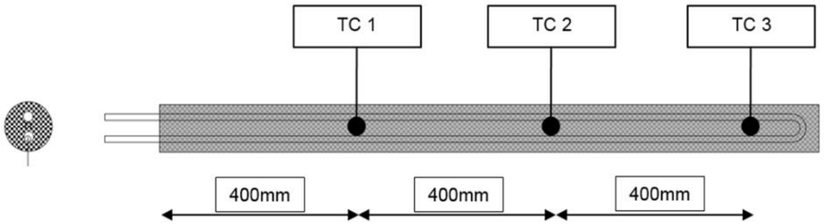


Figure 3.2: Thermocouple (TC) Sensor Positions inside Solar Thermal Evacuated Tube with PCM.

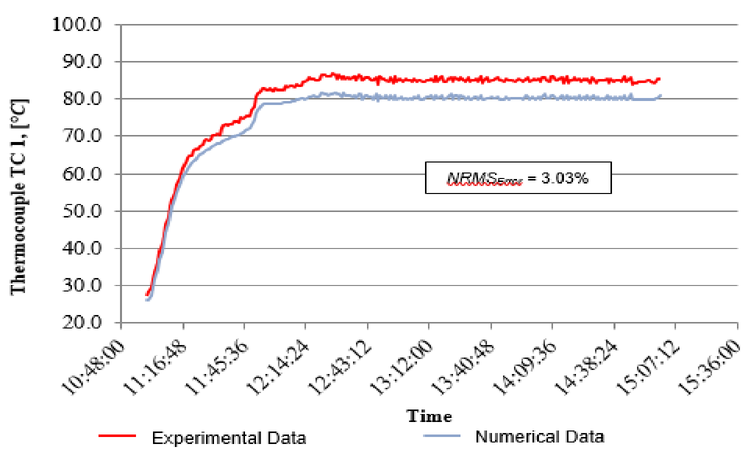


Figure 3.3: Experimental and Numerical Comparison of Thermocouple TC 1 Temperature Results. (Mass flow rate of 2.217×10^{-4} kg/s)

Result and Discussion

- parametric studies on design parameters of the solar thermal evacuated, two design parameters were taken into considerations - length and diameter of the PCM tube
- A minimum and maximum range of each parameter were predefined as per Table 4 1.
- Parametric studies was done using design of experiment (DOE) method.
- Central composite design (CCD), nine design points were generated based on the minimum and maximum values of each design parameters. These nine generated design points are presented as per diagram in figure 4.1.

TABLE 4.1: MINIMUM AND MAXIMUM VALUE OF DESIGN PARAMETERS.

Parameter	Designation	min	average	max
length [mm]	P1	1250	1750	2250
diameter [mm]	P2	32.1	38.1	44.1

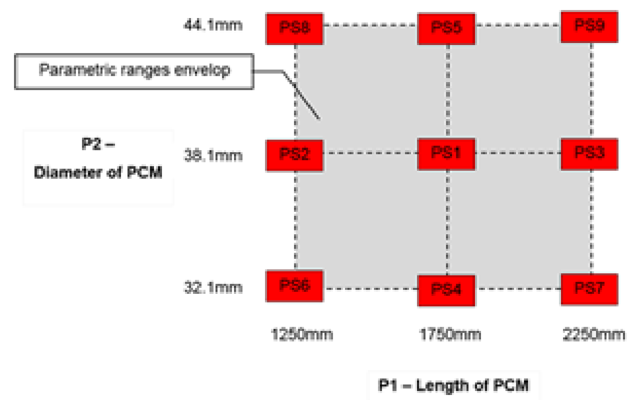


Figure 4.1: Design Points generated from CCD Design Method.

Designation	P1-LENGTH	P2-DIAMETER
PS1	1750	38.1
PS2	1250	38.1
PS3	2250	38.1
PS4	1750	32.1
PS5	1750	44.1
PS6	1250	32.1
PS7	2250	32.1
PS8	1250	44.1
PS9	2250	44.1

Result and Discussion

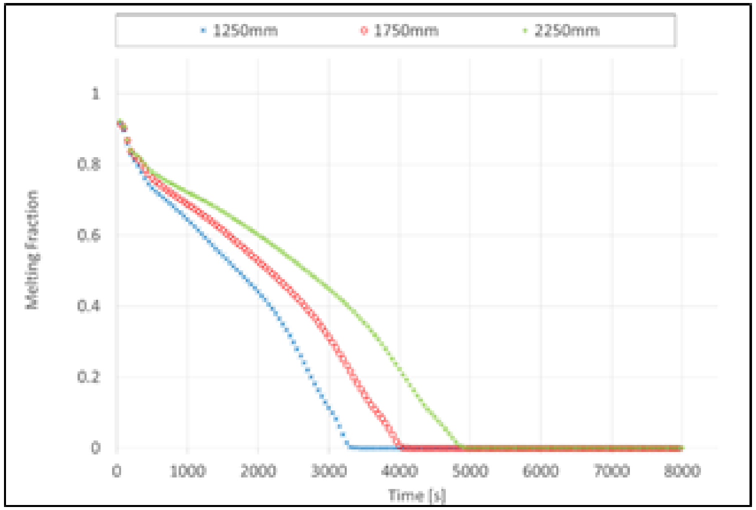


Figure 4.2: Effect of Length of PCM tube to Melting Fraction.

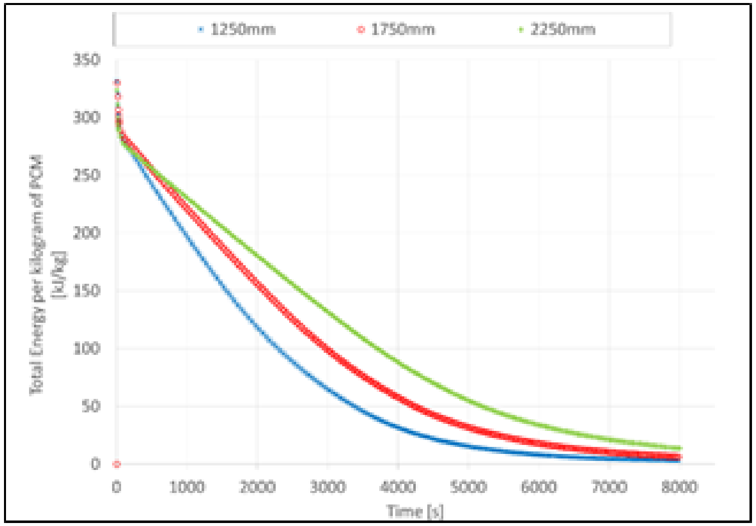


Figure 4.3: Total Specific Energy Storage Comparison for Different Tube Length.

* Tube Diameter is fix at 38.1mm

Table 4.2: Effect of Length of PCM tube Melting Fraction t_0.05MF

Design	Tube Length mm	Time to reach t_0.05MF (s)
PS1	1750	3870
PS2	1250	3180
PS3	2250	4670

-the longer PCM tube length, t_0.05MF is higher. This is mainly due to the increase of PCM mass which is directly proportional to the tube length.

Table 4.3: Total Specific Energy Storage Comparison for Different Tube Length t_(10%TSES)

Design	Tube Length mm	Time to reach t_(10%TSES)
PS1	1750	4958
PS2	1250	3396
PS3	2250	6053

-the longer PCM tube design, it have not only higher capacity to store more energy, but also it take longer duration to deplete its energy storage while still maintaining high water outlet temperature

Result and Discussion

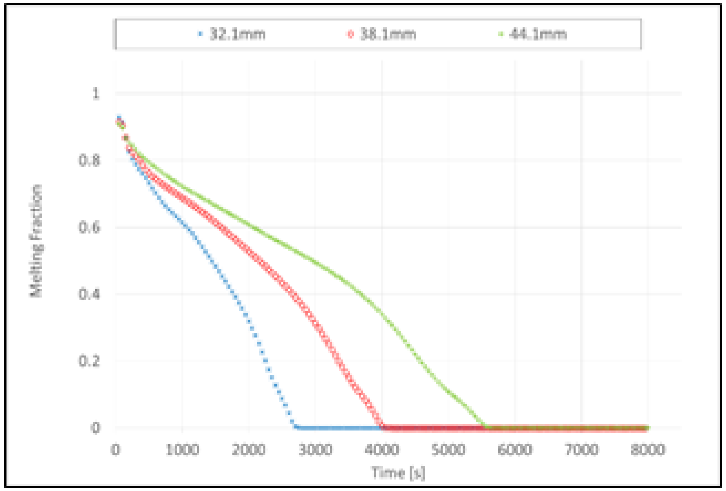


Figure 4.4: Effect of Diameter of PCM tube to Melting Fraction.

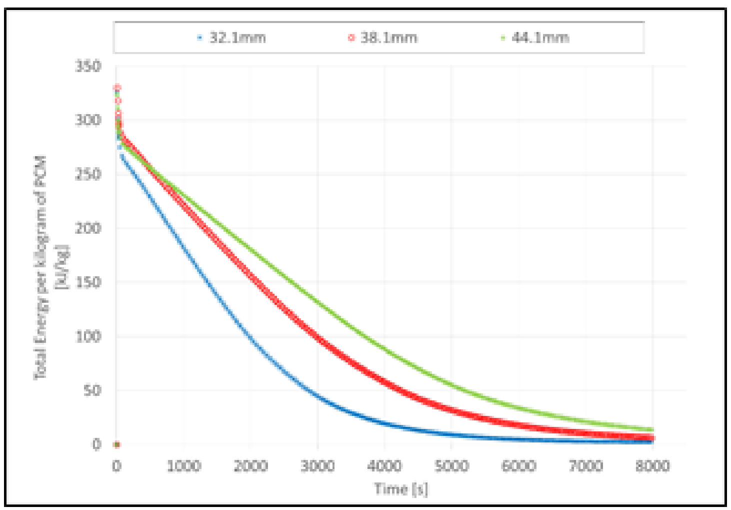


Figure 4.5: Total Specific Energy Storage Comparison for Different Tube Diameter.

* Tube Length is fix at 1750mm

Table 4.2: Effect of PCM tube Diameter to Melting Fraction t_0.05MF

Design	Tube Diameter mm	Time to reach t_0.05MF (s)
PS4	32.1	2590
PS1	38.1	3870
PS5	44.1	5340

where PCM tube discharging thermal performance are highly dictated by the mass of PCM

Total energy stored per kilogram of PCM, t_(10%TSES) as per shown in figure 4.5. t_(10%TSES) obtained for PS5 is the highest with 6808s compared to 4958s for PS1 and 3451s for PS4.

This implied that the larger the diameter of the PCM tube, it is able to withstand longer duration to deplete its energy storage while still maintaining longer high water outlet temperature.

Result and Discussion

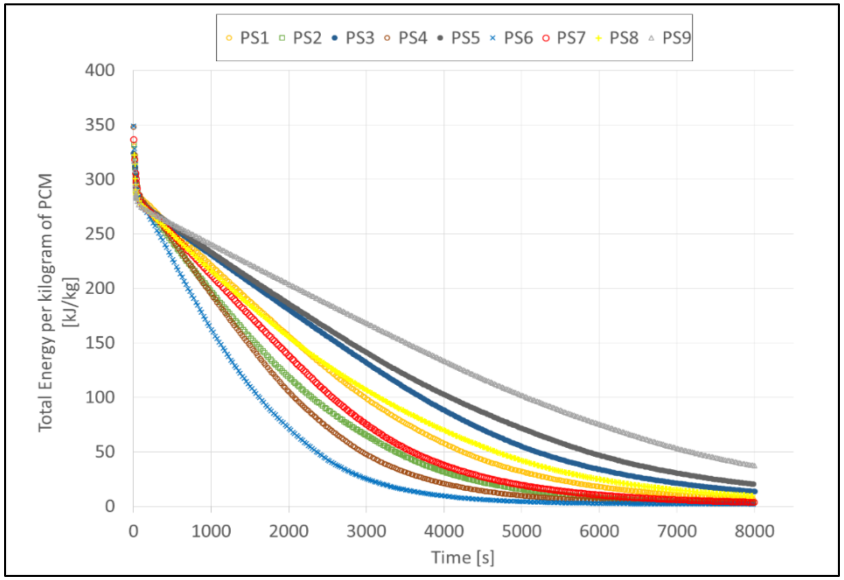


Table 4-3: Summarize Table of Simulation Results of Each Design Points

Name	Length [mm]	Diameter [mm]	Time Required to reach 0.05 of Melting Fraction [s]	Time Required to reach 333K of Water Outlet Temperature [s]	Time Required to reach 10%* of Total Specific Energy Stored [s]
PS1	1750	38.1	3870	3470	4958
PS2	1250	38.1	3180	2300	3396
PS3	2250	38.1	4670	4630	6053
PS4	1750	32.1	2590	2370	3451
PS5	1750	44.1	5340	4620	6808
PS6	1250	32.1	2150	2370	2754
PS7	2250	32.1	3120	3170	4213
PS8	1250	44.1	4390	2970	5449
PS9	2250	44.1	6460	6260	8000

Table 4-2: Summarize Table of PCM Tube Intrensic Property of Each Design Points

Name	Length [mm]	Diameter [mm]	PCM Mass [kg]	PCM Volume [m^3]	Outer Surface [m^2]	Surface to U-tube [m^2]
PS1	1750	38.1	1.344	1.74E-03	0.209	0.105
PS2	1250	38.1	0.96	1.25E-03	0.150	0.075
PS3	2250	38.1	1.728	2.24E-03	0.269	0.134
PS4	1750	32.1	0.898	1.17E-03	0.176	0.105
PS5	1750	44.1	1.866	2.42E-03	0.242	0.105
PS6	1250	32.1	0.642	8.34E-04	0.131	0.075
PS7	2250	32.1	1.155	1.50E-03	0.227	0.134
PS8	1250	44.1	1.333	1.73E-03	0.173	0.075
PS9	2250	44.1	2.399	3.12E-03	0.312	0.134

Parametric Sensitivities

As results in chapter indicated, 4.1 and 4.2, both parameter studied, PCM tube length and PCM tube diameter are directly proportional to the discharging thermal performance of the PCM tube as solar thermal energy storage. Thus, parametric sensitivities or also known as impact factor is studied to identify which one of these two parameters have the highest impact towards a better discharging thermal performance in the solar thermal energy storage using PCM tube.

Result and Discussion

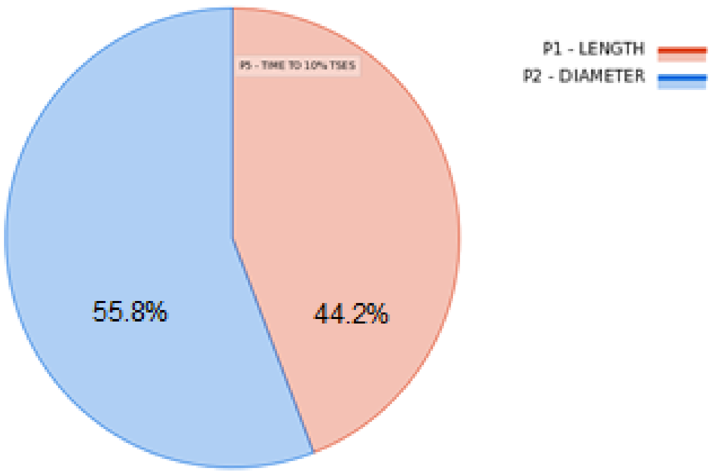


Figure 4.12: Sensitivity of Each Design Parameter toward Time Required to Reach 10% of Total Specific Energy Storage.

Table 4-4: Design Points Extrensic Property Table

Aspects	Opt Design		Initial Design
	Predicted using MOGA	Simulated Data	Simulated Data
Time Required to reach 0.05 of Melting Fraction [s]	4288 (-1.7%)	4360	3870
Time Required to reach 333K of Water Outlet Temperature [s]	3061.7 (-1.6%)	3110	3470
Time Required to reach 10%* of Total Specific Energy Stored [s]	5250.6 (-2.7%)	5394	4958

*10% of max specific energy storage is 33.2kJ/kg.

The studies, were later exported surface module in ANSYS workbench 17.2 for design optimization.

Optimization is define using a multi-objective genetic algorithm (MOGA) method. It is to maximize the time required to reach 10% of total specific energy stored.

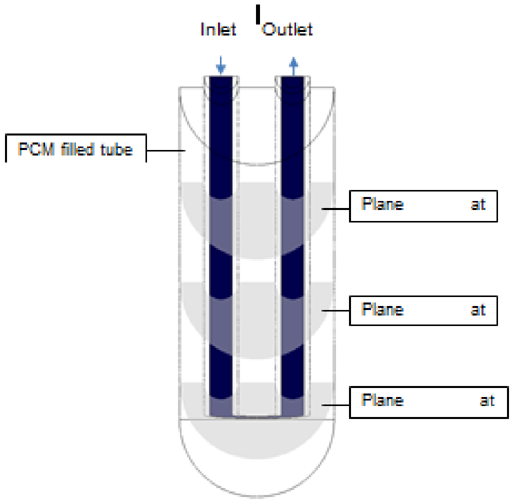


Figure 5.2: Half Cut of PCM Tube Schematic

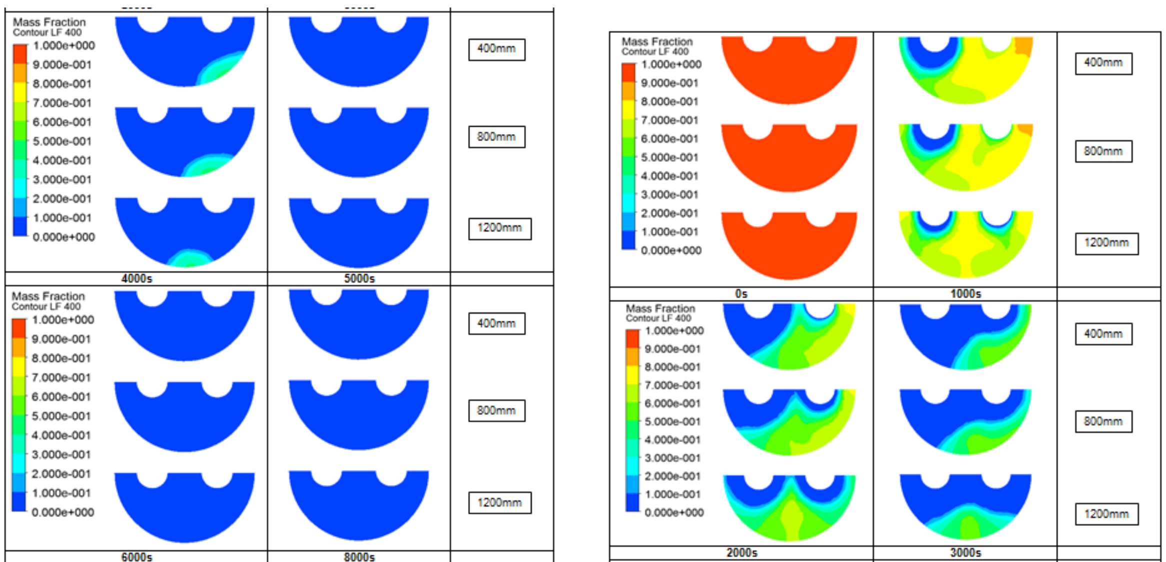


Figure 5.3: PCM Melting Fraction Progression during Discharging Process

Result and Discussion

Conclusion

By fulfill the predetermined optimization objectives, an optimal design of LTHES is proposed. The new design has improvements on the thermal performance of the collector tube with PCM energy storage .

The largest contribution of this study is to provide basic input on the capability of solar energy collector tubes by integrating PCM phase change material as LTHES. It can be used as a reference basis for the development and improvement of systems or designs for future researchers

With combining of renewable energy and Thermal Energy storage there is a potential of increasing the efficiency of having cost effective and sustainable energy producing mechanism

In terms of governmental policy this effort could be very potential in being part of helping our Government effort to combat climate change and become carbon neutral country by the year 2050

With this regard more investment the research and development should be consider by the government.


TODAY
TOMORROW
Don't lose hope.
(You never know what tomorrow will bring.)

Thank You… ☺